

1

CONTROLLER FOR AN ASSISTIVE EXOSKELETON BASED ON ACTIVE IMPEDANCE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from the following U.S. provisional patent application, which is hereby incorporated by reference: Ser. No. 60/888,035, filed on Feb. 2, 2007, entitled "Controller for an Assistive Exoskeleton Based on Active Impedance."

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to controlling an exoskeleton such that it can provide forces to assist a user's motion. One use of these forces is to reduce the muscular effort involved in ordinary motions of the lower extremities, such as walking, climbing stairs, sitting down and standing up. Said forces can also enhance the user's agility of movement. More particularly, the present invention relates to an innovative form of exoskeleton control based on producing a virtual modification of the mechanical properties of the user's extremities.

2. Description of Background Art

Most of the current implementations of assistive exoskeletons are still at the stage of research and development. Commercially available exoskeletons do not yet exist, although a number of groups are working towards them. Most of the existing designs function well only within a laboratory environment and require extensive adjustment and tuning by specialized personnel.

Exoskeleton designs can be classified in terms of their assistive capabilities as either passive or active devices. A passive device is one that cannot deliver more energy to the environment than it has previously drawn from the environment. Springs are an example of a simple passive mechanical device. Exoskeletons that display passive behavior thus have a limited assistive capability. Specifically, they can help the user employ his own muscle power more effectively, but they don't actually supply energy to the user. (In fact, they always draw a certain amount of energy from the user.)

One example of exoskeleton-based passive assist is passive gravity support where the exoskeleton supports part of the user's weight. However, the exoskeleton cannot contribute to raise the user's center of gravity, for example when getting up from a chair. A special case of gravity support is load-carrying assist, in which the exoskeleton supports part of a load carried by the user, for example a heavy backpack. Another passive assist is a force-offsetting assist, where the exoskeleton uses passive devices like springs to offset forces from one healthy body joint (such as the hip) to another body joint that is relatively weak due to some condition (such as the ankle in patients suffering from drop-foot gait). In a resonance-based assist, the exoskeleton modifies the dynamics of the limb to make it function closer to its resonant frequency, thus helping make more effective use of the user's own muscle power.

Active devices on the other hand behave as energy sources. Thus an active exoskeleton has the capability of supplying energy to the user in a continuous way. This is important because, in order to make an exoskeleton an all-purpose assistive device, it should be capable of active behavior. Human movements involve the elevation of the center of mass of the body at one point or another. Only an active device can assist this kind of motion in a repetitive way. Additionally, human motion involves a non-negligible amount of energy dissipa-

2

tion through muscle tissue. An active exoskeleton would provide the capability to supplement part of the energy dissipated by the human body.

Control of an exoskeletal device is a challenging problem.

In the case of active exoskeletons, the prevailing paradigm is myoelectrical control. This control scheme consists of using the muscles' electromyographical (EMG) activity to estimate muscle forces and multiplying the estimated forces by a certain gain. Thus the exoskeleton behaves as an amplifier of muscle forces. This type of control has the appeal of being useful, in principle, to assist any motion attempted by the human. On the other hand, it has several practical limitations, due mainly to the nature of the EMG signal. Accurate estimation of torque from EMG is a challenging task requiring the characterization of several muscles, plus separating extraneous components affecting the EMG signal. Furthermore, EMG displays considerable variability with time and across subjects.

There is a need for an exoskeleton control method that eliminates the need for EMG as a source for the control signal, yet provides the versatility of assist that comes from active behavior.

SUMMARY OF THE INVENTION

A system and method are presented to provide assist to a user by means of an exoskeleton with a controller capable of making the exoskeleton display active impedance. The exoskeleton assists the user by reducing the muscle effort required by the user to move his or her extremities.

In one embodiment, a single-degree-of-freedom (1-DOF) exoskeleton assists a user with single-joint movement using an active impedance controller. In another embodiment, a multiple-degree-of-freedom (multi-DOF) exoskeleton assists a user with multiple-joint movement using an active impedance controller.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings in which like reference numerals refer to similar elements.

FIG. 1 illustrates a schematic representation of a mechanical impedance, according to one embodiment.

FIG. 2 illustrates a 1-DOF assistive exoskeleton for a knee joint, according to one embodiment.

FIG. 3 illustrates a linear model of a 1-DOF exoskeleton, according to one embodiment.

FIGS. 4A, 4B, and 4C illustrate generating virtual impedance parameters in an exoskeleton through impedance control, according to one embodiment.

FIG. 5 illustrates a linear model of a human limb segment, according to one embodiment.

FIG. 6 illustrates a linear model of a system comprising a human limb segment attached to an exoskeleton, according to one embodiment.

FIG. 7 illustrates applying active exoskeleton impedance for scaling of a human limb impedance, according to one embodiment.

FIG. 8 illustrates the effect of pure negative damping on human limb impedance, according to one embodiment.

FIG. 9A illustrates an implementation of a 1-DOF assistive controller based on active admittance, according to one embodiment.